Effect of Substitution of Positive Ion (M^{+2}) on the Physical Properties of M-Fe_2O_4

Nahedh H. Alwash[1,*], Jafer Fahdel Odah[1], Ahmed Namah Mohamed[1]

[1] *Department of Physics, Science college, Al-Muthanna university, Samawa, Iraq*

[*]*Corresponding Author: nh.alwash@yahoo.com*

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Abstract: Cobalt, Manganese and Magnesium ferrites powders have been synthesized using chemical mixing method. Calcination and sintering temperatures were 800°C respectively. The characteristics of spinal ferrite have been investigated by XRD technique while the magnetic characterization samples have been done using vibrating sample magnetometer (V.S.M). The magnetic properties such as initial magnetic permeability, quality factor, inductor factor and power loss density are studied under variation of frequency using L.C.R meter as well. Saturation magnetization, coercive field and remanent magnetization are determined from hysteresis loops for all prepared sample.

Keyword: Ferrites, magnetic properties, initial permeability

1-Introduction:

Ferrimagnetic materials (ferrites) are magnetic ceramics which have wide rang applications for making different devices such as permanent magnets, memory storage devices and microwave ones. Spinel ferrites have been investigated for their useful electrical and magnetic properties. Properties of ferrites are known to be sensitive to the processing technique [1, 2]. Manganese–zinc ferrites are technologically important materials because of their high magnetic permeability and low core losses. These ferrites have been widely used in electronic applications such as transformers, choke coils, noise filters, recording heads and so on [3].

Magnesioferrite ($MgFe_2O_4$) is one of the most interesting, because, due to its small magnetocrystalline anisotropy, super paramagnetic properties are still present at relatively low temperatures and/or high magnetic fields [4]. It is worth to note the cobalt ferrites are spinels and their properties depend on composition. The formation of spinelic solid solutions implies the substitution of the bivalent cation with another bivalent one, or a combination of cations to insure the electrical neutrality of the ensemble. The distribution of the substituting ions in tetrahedral or octahedral sites depends on the ionic radius, charge and electronic configuration of the cations [5].

The spinel structure contains two cation sites for metal cation occupancy. There are 8 A-sites in which the metal cations are tetrahedrally coordinated with oxygen, and 16 B-sites which possess octahedral coordination. When the A-sites are occupied by Me^{+2} cations and the B-sites are occupied by Fe^{+3} cations, the ferrite is called a normal spinel. If the A-sites are completely occupied by Fe^{+3} cations and the B sites are randomly occupied by Me^{+2} and Fe^{+3} cations, the structure is referred to as an inverse spinel [6].

Many basic studies of metal oxide have been completed that relate magnetic response coercivity,saturation,magnetization, ermeability, etc.

The present study is focused on the influence of the metal ion type on the magnetic properties of ferrites, the initial permeability spectra, conductor factor, quality factor, and on the power losses dissipation. Three categories of samples are studied: cobalt ferrite (Co-F), Manganese ferrites (Mn-F) and Magnesium ferrites (Mg-F), respectively.

Experimental part.

The powders of Cobalt ferrites (Co-F), Manganese ferrites (Mn-F) and Magnesium ferrites (Mg-F) are prepared using chemical mixing method. The pH of the solution was adjusted to be 7.5-8.5 using aqueous ammonia. The solution is heated at 100 ˚C with constant stirring to transform it into a gel and then filtered gel is obtained by dehydration process. The dried gel is combusted with the evolution of large amount of gases and it resulted in the formation of loose powder [7]. The prepared powder is then calcined at 800˚C. The three types of prepared ferrite are pressed (5tons/Cm^2) as rings. The temperature of final sintering in this case is kept at 1100˚C.

Magnetic characterization of the samples has been done using vibrating sample magnetometer (VSM) at room temperature. The inductors for these samples are measured using L.C.R type (micro test 6379). By using the same equipment, the resistance of samples is measured at same range of frequencies, which used to calculate the quality factors and power losses dissipation (PLD).

2-Results and discussion:

Figures (1, 2, and 3) show the XRD pattern of Co-F, Mn-F, and Mg-F samples respectively, taken after their sintering at 1100 ˚C. As seen, all these samples show good crystallization, with well-defined diffraction lines. The structure can be indexed as a single-phase cubic spinal structure. It is obvious that the characteristic peaks for spinel ferrites appear in the samples as the main crystalline phase. The peaks (2 2 0), (3 1 1), (2 2 2), (4 0 0), (4 2 2), (5 1 1) and (4 4 0) reflections of the cubic structure correspond to spinal structure.

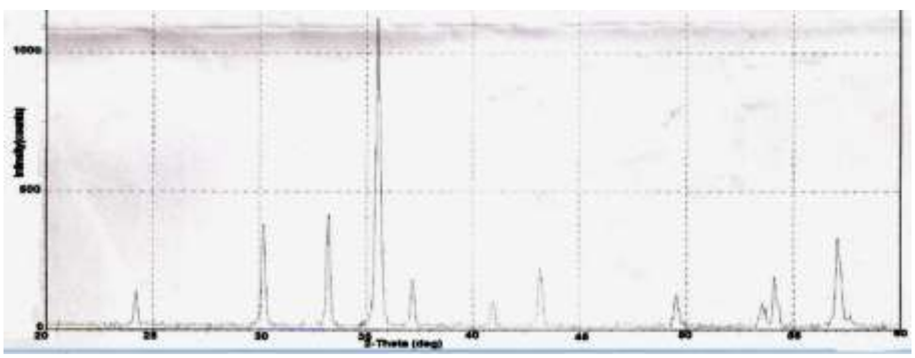


Fig. (1): XRD for Co-F

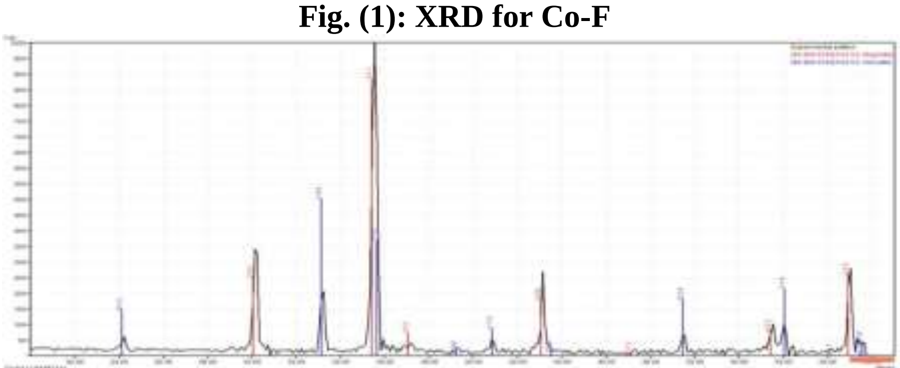


Fig. (2): XRD for Mg-F

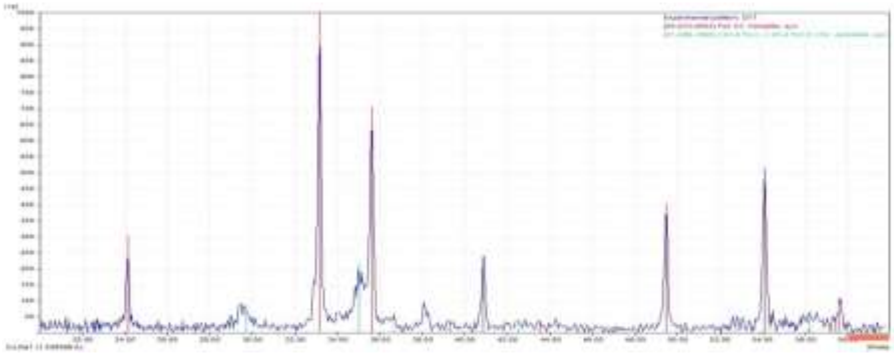
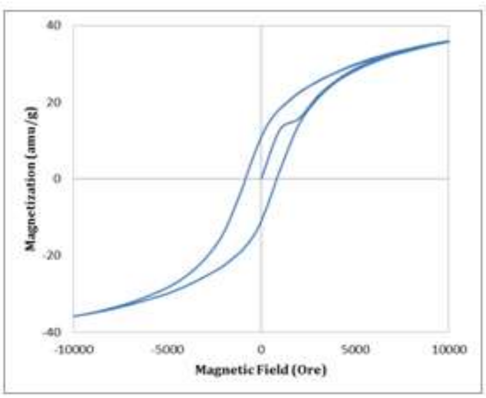


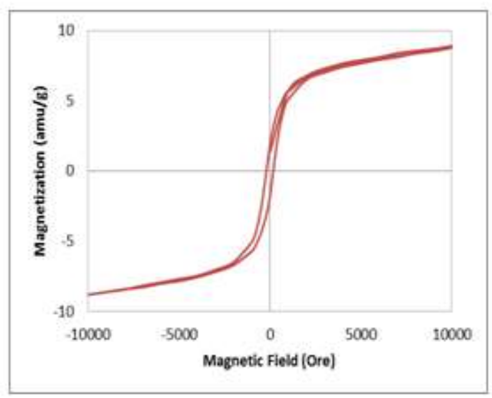
Fig. (3): XRD for Mn-F

The Mossbauer suggested the presence of the iron in the Fe^{+3} oxidation state analyses according to the isomer shift values. The iron excess in sample Co-F is preferentially found in the octahedral positions of the spinel lattice. The manganese or magnesium ions an the second and third samples preferentially substitute iron in the octahedral positions because Fe^{+3} has higher preference for the tetrahedral positions, as compared to the Co^{+2} and Mn^{+3} or Mg^{+3} cations.[8].

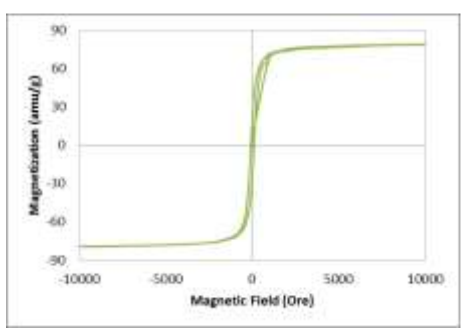
The value of magnetic saturation for Co-F, Mn-F, and Mg-F samples are shown in figure (4) respectively. These figures showing typical magnetic behavior having anon-zero coercivity and remanance.



(a) Co-F



(b) Mn-F



(c) Mg-F

Fig. (4): V.S.M. testing for all samples

The value of magnetic saturation, coercivity and remanance that concluded was shown at table (1). Low area hysteresis curve shows that the material formed is of soft magnetic material [9].

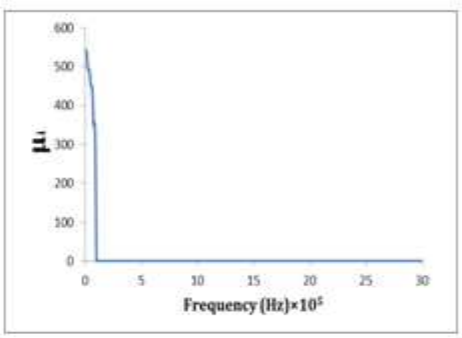
The saturation magnetization (σ_s), coercive field (H_c) and remnant magnetization (σ_r) for the prepared samples are shown in table (1).

Table (1) The saturation magnetization, coercive field and remnant magnetization

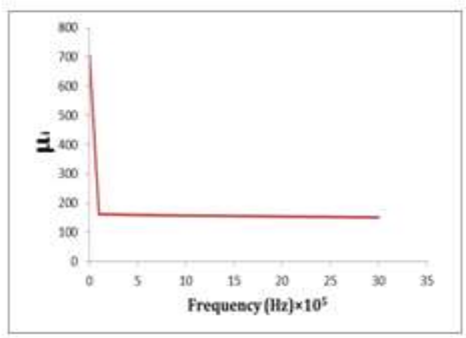
	Mg-F	Mn-F	Co-F
σ_r	4.672	0.585	12.378
σ_s	33.85	25.9	16.5
H_c	21.07	3.364	37.32

It is obvious that both of magnetization and the coercive field of Co-F is greater than that of Mn-F which may be attributed to the magnitude of the magnetic moments of Co^{+2} which is greater than that of Mn^{+2}. Furthermore the high value of Hc for cobalt ferrite compared to the other prepared ferrites could be interpreted in the light of one ion model [10]. Also it is evident from Table 1 that Hc is high for Co-F than the other ferrites due to the highly substitution of Co^{+2} ions is because of the high exchange interaction energy and relatively higher orbital contribution of Co^{+2} ions for the magnetic moment [11]

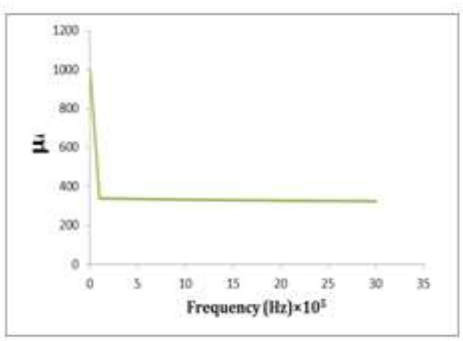
The initial magnetic permeability is a very sensitive property. The shape of the experimental permeability spectra for Co-F, Mn-F, Mg-F samples is a normal one. This permeability was calculated using LCR by calculating the values of the inductors. The permeability of prepared samples are shown in figure (5) as a function of frequency. It is clear from these figures that the permeability of the all samples decreases with increasing frequency.



(a) Co-F



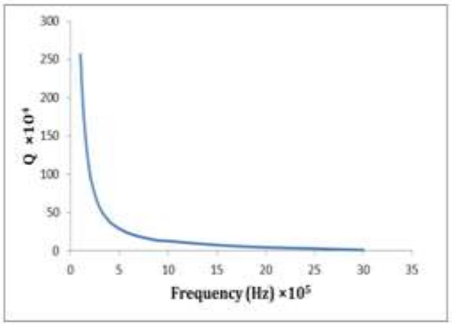
(b) Mn-F



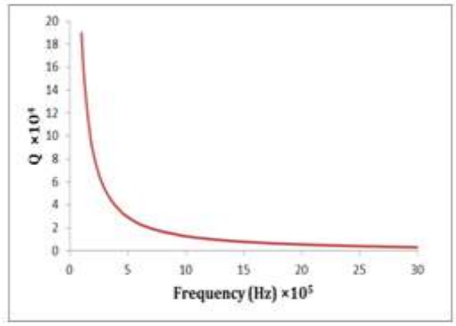
(c) Mg-F

Figure (5) Variation of magnetic permeability behavior with frequency for all samples

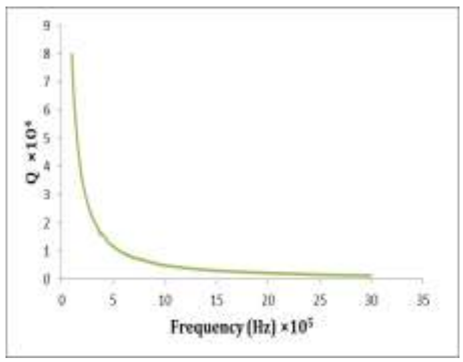
Figure (6) show the dependence of quality factor (Q-factor) on the frequency domain for the Co-F, Mn-F, and Mg-F samples respectively. The result shows that the Q-factor increases with increasing frequency from 1 KHz to 24 MHz and after this frequency Q-factor decreases. The maximum value of Q-factor at 24 MHz is 64.



(a) Co-F



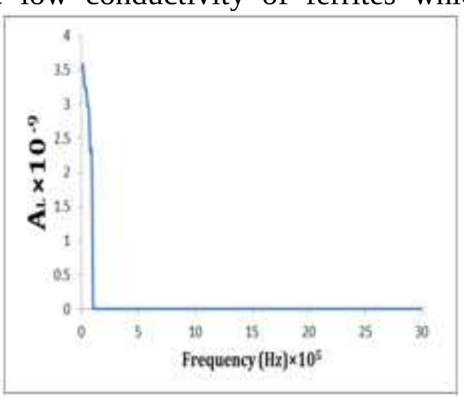
(b) Mn-F



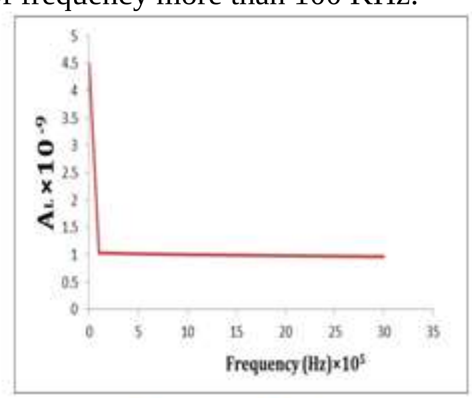
(c) Mg-F

Fig. (6): Quality factor for all samples

Figure (7) shows the variation of the inductor factors (A_L) of the ring ferrite samples with the frequency. At low frequencies the inductor factor decreases rapidly up to 100 KHz due to the low conductivity of ferrites which caused eddy currents strongly weaken the magnetic field in the core end that leads to decrease the inductance. At high frequencies one can observe that the inductor factor independent of frequency more than 100 KHz.



(a) Co-F



(b) for Mn-F

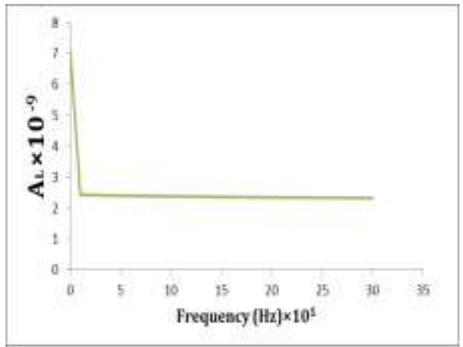
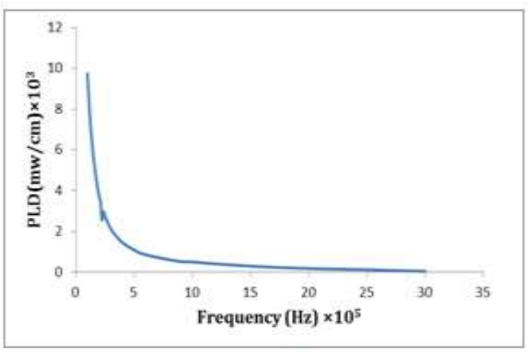


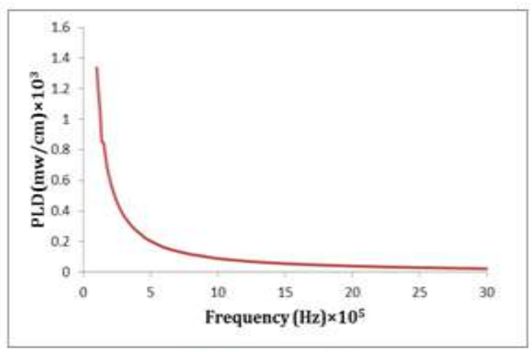
Fig. (7): The variation of the inductor factors for all samples

As shown in Figure (7), the inductors (AL) for Mg-F ferrite composite have higher inductance factor than the corresponding of Mg-F and Co-F ferrites composite, corresponding to the magnetization and applied magnetic field characteristics of the tested ferrites materials.

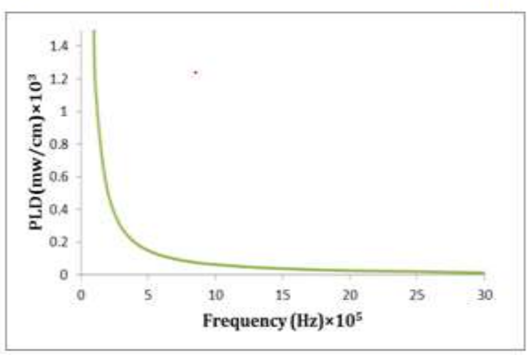
Figure (8) shows the variation of power loss density (PLD) of the prepared ferrites with frequency. The loss is due to lag of domain walls motion with respect to the applied alternating magnetic field and is attributed to imperfections in the lattice. The results revel that (PLD) decreases initially with frequency reaching a minimum value, and then it will be stationary when the frequency is increased.



(a) CO-F



(b) for Mn-F



(c) for Mg-F

Fig. (8): Power losses density for all samples

the variation of (PLD) for Co-F at different frequencies shown in fig (8) has the highest values than both Mn and Mg ferrites, this may be attributed to evident from the variations that tan δ is decreasing with an increasing substitution of Co^{2+} ions. The major contribution to the (PLD) in ferrites is due to hysteresis losses [12], which in turn are based on damping phenomenon associated with irreversible wall isplacement and spin rotations. However, the hysteresis loss becomes less important in the high-frequency range ecause the wall displacement is mainly damped and the hysteresis loss will be due to spin rotation. The values of (PLD) are found to be small even at higher frequencies for these samples, which is one of the criteria for the materials used in microwave devices.

3-Conclusion:

Chemical mixing method is a good and simple one to synthesize cobalt, Manganese and Magnesium ferrites powders. All these sample show good crystallization with well-defined line in XRD pattern. From the magnetization hysteresis loops, the behavior is shown a non-zero coercivity and remanance for all samples. However one can conclude that Co-F is a hard ferrite while the other are soft one. All the magnetic properties have the same behavior with the variation of frequency but with some differences in the intensity of these properties.

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